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RECONNAISSANCE GEOLOGY AND STRUCTURE OF THE COSO RANGE, CALIFOR--ETC(U)
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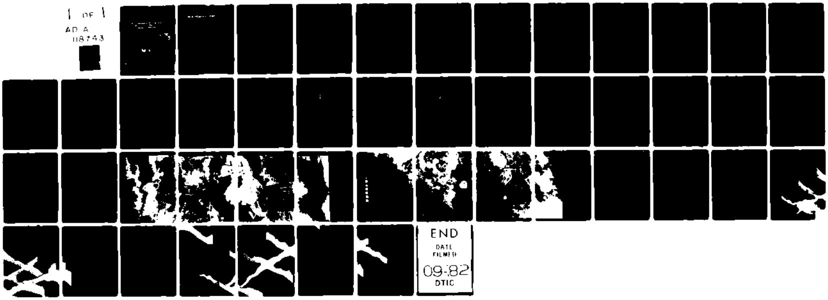

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Reconnaissance Geology and Structure of the Coso Range, California

by
Glenn R. Roquemore
Research Department

MAY 1982

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FOREWORD

This report details work begun in 1974 by the author while a graduate student at California State University, Fresno, and completed in 1981 while employed at the Naval Weapons Center. This work was carried out under Task No. ZR00001.

The study was made to provide a data base on the rock type, rock chemistry, and structural relationships in the Coso Range. Various range tests require specific geologic terrain or rock type. Also, the siting of permanent structures should be accomplished within the constraints of the natural geologic hazards environment.

This report was reviewed for technical accuracy by Wendell Duffield and Charles Bacon, both of the U.S. Geological Survey.

Approved by
E. G. ROYCE, *Head*
Research Department
6 January 1982

Under authority of
J. J. LAHR
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(U) *Reconnaissance Geology and Structure of the Coso Range, California*, by Glenn R. Roquemore. China Lake, Calif., Naval Weapons Center, May 1982. 26 pp. (NWC TP 6036, publication UNCLASSIFIED.)

(U) The Coso Range was mapped at a scale of 1:62,500 in order to collect basic petrographic, petrologic, and chemical data. Special attention was given to individual fault zones and regional fault patterns. The basement in the Coso Range consists of Mesozoic age granitic rock and metamorphic inclusions. Tertiary aged dacite tephra and flows cover the northern and western parts of the Range. Quaternary basalts, andesites, and rhyolites cover the central and eastern parts of the Range.

(U) The Coso Range has been broken by Basin and Range extensional faulting, as seen in extensive horst and graben development and right-slip displacement evidenced by ramping, oblique-slip striations, and lateral-slip fault morphology.

CONTENTS

INTRODUCTION

LOCATION OF STUDY AREA

The Coso Range is located in eastern California, in the southwestern corner of the Basin and Range Physiographic Province. The mountains encompass 750 square miles; to the west is the Sierra Nevada, and to the east is the Argus Range. Owens Lake terminates the Coso Range to the north, and the Indian Wells Valley forms the boundary to the south (Figure 1).

The study area is approximately 140 miles north of Los Angeles and is almost entirely within the confines of the Naval Weapons Center, China Lake. The area is accessible by Highway 395 into Rose Valley. A partially paved road then leads eastward from Coso Junction into the area. Permission must be obtained from the U.S. Navy before entry.

The Coso Range lies within an arid climatic province, and temperatures are in excess of 110°F in the summer and drop to about 15°F in the winter. The average annual rainfall is slightly more than 2 inches in the valleys and 5 to 6 inches in the uplands; precipitation falls mostly from October through March.

The vegetation, which is generally xerophytic, includes Joshua trees, greasewood, creosote, and sagebrush. Pinon pines grow at higher elevations.

PURPOSE OF INVESTIGATION

To better understand the geothermal system of the Coso Range, the area was mapped (1:62,500 scale) and the major geologic units characterized (chemically and petrographically) with an emphasis on structure. Field work, laboratory analysis, petrology, and petrography were accomplished sporadically between 1974 and 1976. Part of the data was presented in a master's thesis by Roquemore.[1] At the onset of the study, the only available geologic mapping of the area was by Moyle,[2] who mapped an area around the Coso volcanic field in conjunction with ground water studies for the Navy, and mapping of the Keeler and Haiwee Reservoir quadrangles by Stinson of the California Division of Mines and Geology.

This report includes reconnaissance geologic mapping of part of the Coso Range with some petrology, petrography, and chemical analyses. Emphasis is placed on structural geology; i.e., fault displacement, sense of movement, and fault pattern.

[1] G. R. Roquemore. "Cenozoic History of the Coso Mountains as Determined by Tuffaceous Lacustrine Deposits." Master's thesis, California State University, Fresno, 1977. 65 pp. Thesis UNCLASSIFIED.

[2] W. F. Moyle, Jr. *Wells, Springs, Fumeroles, and Hydrothermal Power Potential of the Coso Hot Springs Area, California*. (U.S. Geological Survey Open File Report (in process), UNCLASSIFIED.)

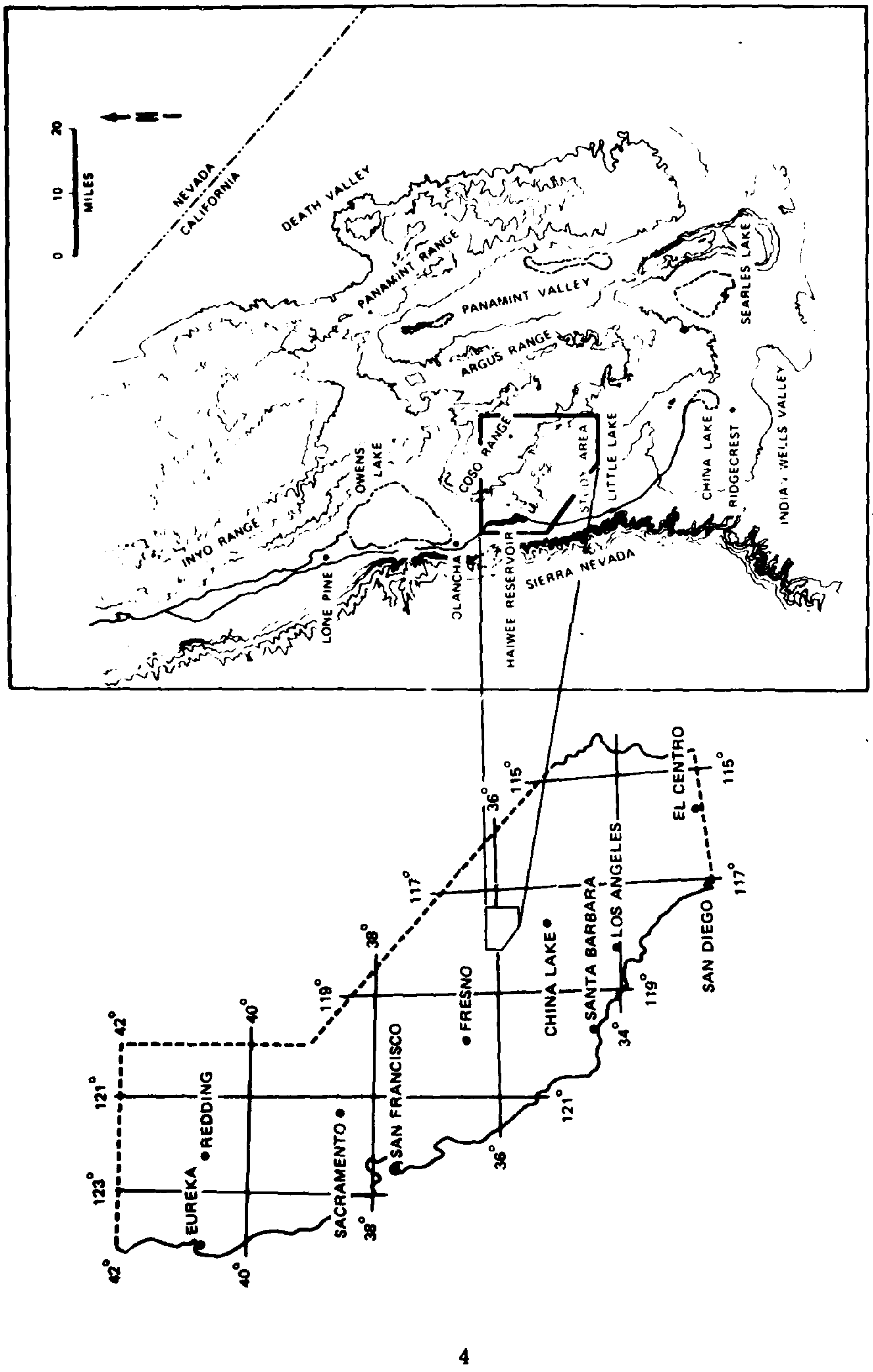

FIGURE 1. Index Map of Study Area.

Detailed geologic mapping, petrology, and petrography of the Coso Range are presently available (Stinson and Duffield and Bacon).[3,4]

DESCRIPTION OF MAJOR ROCK UNITS

BASEMENT ROCK

The bedrock of the Coso Range (gr, Plates 1 and 2) consists of granite, granodiorite, quartz monzonite, and diorite similar to that of the Sierra Nevada a few miles to the west. The contact relationships and detailed distribution of these various rocks have yet to be studied. Their ages have not been determined, but because of their similarity with the Cathedral Peak suite, they are considered correlatives and determined to be between 50 000 000 and 180 000 000 years old, using the potassium-argon (K-Ar) dating method (Evernden and Kistler).[5] Metamorphic rocks occur as xenoliths within the granitic rocks. Generally, the metamorphics are dark, schistose, contorted, and often infused with granitic material. These rocks are regarded to be late Paleozoic or Mesozoic in age (von Huene).[6]

The granitic rock in the area is generally a coarse-grained, light-colored granite, with a hypautomorphic-granular texture. The rock is composed of subhedral to anhedral grains of alkali feldspar, plagioclase (An 25-35), quartz, and biotite. Diorite, hornblende gabbro, and other basic rocks occur as both xenoliths and dikes. Aplitic dikes in the area are composed of 40% quartz, 30% orthoclase, 25% albite, 4% microcline, and some minor ferromagnesian minerals.

Hornblende-gabbro inclusions in the granite are roughly circular in shape and range from 6.0 to 7.5 meters in diameter. Locally the hornblende crystals are 2.6 centimeters or more in length and are inclosed in a fine-grained, greenish to light gray groundmass. The gabbro is composed of approximately 42% hornblende, 28% augite, 25% labradorite, and minor apatite, titanite, magnetite, and zircon. In thin section the inclusions show extensive recrystallization.

Diorite usually occurs in small elongated outcrops. In some areas the diorite becomes the major intrusive unit that has been recrystallized to the point of a diorite schist. The feldspar, biotite, and hornblende show lineal arrangement and uniform grain size.

VOLCANIC AND SEDIMENTARY ROCKS

Eruptions of rhyolite, basalt, and cinder cover about 70 square miles of intrusive and sedimentary rocks in the Coso and Argus Ranges.[6] The volcanic flows aggregate several hundred meters in thickness and are mostly basalt, andesite, and dacite interbedded in a few places with scoria and pumice. A basalt flow is interbedded with sedimentary rocks of the

[3] M. C. Stinson. *Geologic Map and Sections of the Keeler 15-Minute Quadrangle, Inyo County, California.* 1977. (California Division of Mines and Geology Map Sheet 38, 1:62,500, UNCLASSIFIED.)

[4] W. A. Duffield and C. R. Bacon. *Geologic Map of the Coso Volcanic Field and Adjacent Areas, Inyo County, California.* 1981. (U.S. Geological Survey Miscellaneous Investigations Series Map I-1200, 1:50,000, UNCLASSIFIED.)

[5] J. F. Evernden and R. W. Kistler. *Chronology of Emplacement of Mesozoic Batholith Complexes in California and Western Nevada.* 1970. P. 42. (U.S. Geological Survey Professional Paper 623, UNCLASSIFIED.)

[6] R. E. von Huene. "Structural Geology and Gravimetry of Indian Wells Valley, Southeastern California." Ph.D. dissertation, University of California, Los Angeles, 1960. Dissertation UNCLASSIFIED.

Pleistocene Coso Formation (Zbur).[7] The volcanic rocks appear to be derived from volcanic vents and fissures that are distributed throughout the Coso Range. von Huene described 9 cinder cones in the Mountain Springs quadrangle and 17 basaltic and 2 rhyolitic cones in the Little Lake quadrangle as centers of eruptions and flows.[6]

The basalt in the Coso area is composed of thin laths of labradorite and rounded grains of augite in an extremely fine-grained matrix of feldspar and some ferromagnesian minerals. The rock is generally composed of 20% labradorite laths, 10% augite, and the groundmass forming 70% of the rock. Opaque minerals make up approximately one-third of the groundmass. When the geologic map was printed, very few K-Ar dates were available. Recent K-Ar dates (Lanphere and Dalrymple)[8] indicate that unit Qv (Plates 1 and 2) contains rocks that are both Quaternary and Tertiary. Duffield and Bacon have since mapped both Quaternary and Tertiary volcanic flows.[4]

Basalt flows that are 2 000 000 to 3 000 000 years old are common throughout the Coso Range (Qv, Plates 1 and 2). The flows of Wild Horse Mesa in the southeastern part of the study area are very extensive and cover granitic basement as well as lapilli-tuff deposits (Tplt, Plate 1) exposed in some canyons. These basalts are broken into north-south trending blocks by normal faults (Plate 2).

Younger basalts crop out at and near Volcano Peak. Basaltic cones are found southwest of the map area. Volcano Peak is the largest and highest of these cones, and few signs of erosion are apparent. However, the K-Ar date is 0.038 ± 0.032 million years.[8]

The silicious rocks in the area range from rhyolitic domes displaying good flow structure to pumice and obsidian ejecta. The rhyolite is generally composed of a large amount of glass with a few small grains of quartz, sanidine, and biotite flakes. Vesicles in the rhyolite are elongated, and much of the glass appears as long fibers that bend around the mineral grains.

The rhyolitic domes generally occur in a linear arrangement, trending north-south. At the southern end of this alignment, the rock is dense, fine-grained, and light gray. Approximately 20% of the rock is composed of quartz phenocrysts, with orthoclase phenocrysts present at 5%. Both kinds of phenocrysts average 2 millimeters in diameter.

The Coso volcanic field contains 30 or more rhyolitic domes (Qr, Plate 1) in all stages of development. The K-Ar dates range from 0.044 ± 0.022 to 1.04 ± 0.02 million years (Duffield, Bacon, and Dalrymple).[9] Most of these domes are still surrounded by lapilli rings (Qpr, Plate 1). Chesterman described several pumice deposits associated with 2 000 000- to 3 000 000-year-old lapilli-tuffs (Tplt, Plate 1) in the Coso area.[10] The Coso Formation crops out along the western and northern flanks of the Coso Range (Tc, Plates 1 and 2). According to Hopper, the Coso Formation consists of alluvial gravels, overlying tuffs, and lake beds and is over 150 meters thick.[11] These rocks rest on an erosional surface cut into granite and are in places concordantly overlain by flows of olivine basalt (Qv, Plates 1 and 2).

[7] U.S. Naval Ordnance Test Station. *A Geophysical Investigation of Indian Wells Valley, California*, by R. T. Zbur. China Lake, Calif., USNOTS, July 1963. (NOTS TP 2795, publication UNCLASSIFIED.)

[8] M. A. Lanphere and G. B. Dalrymple. "K-Ar Ages of Pleistocene Rhyolitic Volcanism in the Coso Range, California," *Geology*, Vol. 3 (1975), pp. 339-341.

[9] W. A. Duffield, C. R. Bacon, and G. B. Dalrymple. "Late Cenozoic Volcanism, Geochronology, and Structure of the Coso Range, Inyo County, California," *J. Geophys. Res.*, Vol. 85, No. 5 (1980), pp. 2381-2404.

[10] Charles W. Chesterman. "Pumice, Pumicite and Volcanic Cinders in California," *Calif. Div. of Mines Bull.*, Vol. 174 (1956), pp. 62-68.

[11] Richard H. Hopper. "Geologic Section From the Sierra Nevada to Death Valley, California," *Geol. Soc. Am. Bull.*, Vol. 58 (1947), pp. 393-432.

CHEMICAL ANALYSES

SAMPLING

The samples for this study were collected over a 3-month period in 1975 to represent each major rock type in the area. Sampling included major volcanic units and granitic bedrock. Dikes and inclusions were also sampled and analyzed. The sample numbers on the geologic map (Plate 1) represent samples taken for petrographic analysis. Some of those samples were chemically analyzed and received different sample numbers. A sample number correlation table is presented as Appendix A.

CHEMISTRY

The chemical analyses were conducted by Rocky Mountain Geochemical Corp., Midvale, Utah, and Hornkohl Laboratories, Inc., Bakersfield, Calif.

ANALYSES

The analyses for the pumice lapilli-tuff in the Coso Range are given in Table 1. Major oxides and CIPW Norms* (Table 2) of all nine samples are similar. Samples 1 and 2 occupy the same stratigraphic position. The pumice lapilli-tuff deposits in each of these localities are capped by a basalt flow that is texturally and mineralogically the same at each outcrop. Sample 3 is found east of Cactus Flat in the Ray Gill 31 quarry and is one of the deposits that crops out nearest Haiwee Ridge. Sample 4 crops out above the Wild Horse Mesa basalt (Babcock).[12] The texture, amount of biotite, and the chemistry show similarities between each pumice lapilli-tuff deposit. Samples 5, 6, and 7 are from the Donna deposit. Sample 5 is the highest stratigraphic unit, and sample 7 is the basal tuff unit. Although unit C (or sample 7) is partially air fall, chemically and petrographically it is identical to the upper two reworked units. Samples 8 and 9 are found in Coso Valley and crop out above the Wild Horse Mesa basalt. Sample 8 is the highest stratigraphic unit, and sample 9 is the basal tuff unit that lies in part on a dark brown paleosol. The chemistry of these samples indicates a single magma source; however, each unit is stratigraphically separated by a slight change in bedding characteristics that could have easily been caused by a change in wind direction during the eruption. The term bedding when applied to the Coso Valley outcrop refers to minor sorting variations since this deposit is predominantly air fall.

Based on Miyashiro's SiO_2 versus FeO/MgO plot, all of the pumice lapilli-tuff units analyzed are dacitic, although the petrography indicates an andesitic composition.

The major oxides and the CIPW Norms of representative volcanic rocks from the Coso Range are given in Tables 3 and 4. These samples were analyzed to determine the genetic relationship of the pumice lapilli-tuff to other volcanic rocks in the area. Sample 33 (Table 3) is the analysis of the Haiwee Ridge andesite. It can be seen that the pumice lapilli-tuff units in

* Cross, Iddings, Pirsson, Washington Norm system of classifying igneous rocks.

[12] J. W. Babcock. "The Late Cenozoic Coso Volcanic Field, Inyo County, California." Ph.D. dissertation, University of California, Santa Barbara, 1977. 213 pp. Dissertation UNCLASSIFIED.

TABLE 1. Major Oxide Analyses of the Pumice Lapilli-Tuff, Coso Volcanic Field.

Major oxide	Sample, wt. %								
	1	2	3	4	5	6	7	8	9
SiO_2	64.70	66.31	66.55	65.83	67.45	66.61	67.00	67.76	66.89
TiO_2	0.49	0.50	0.50	0.48	0.47	0.49	0.48	0.53	0.53
Al_2O_3	16.14	15.86	16.61	16.11	15.51	16.78	16.05	15.92	16.53
Fe_2O_3	2.11	2.09	2.14	2.07	2.05	2.12	2.08	2.15	2.16
FeO	0.52	0.39	0.62	0.61	0.61	0.42	0.42	0.58	0.59
MnO	1.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
MgO	1.51	1.57	1.22	1.49	1.30	1.34	1.41	1.24	1.34
CaO	4.45	4.73	3.36	4.82	4.21	3.71	3.79	3.46	3.57
Na_2O	4.62	4.54	4.26	4.45	4.53	4.87	4.89	3.87	4.24
K_2O	3.63	3.70	4.37	3.60	3.58	3.35	3.61	4.19	3.80
P_2O_5	0.26	0.20	0.27	0.43	0.16	0.20	0.17	0.20	0.23
Total	99.93	99.94	99.95	99.94	99.92	99.94	99.95	99.95	99.93

NOTE: Explanation of column headings:

1 Calc-alkalic dacite from Renegade Canyon
2 Calc-alkalic dacite from Deadman Canyon
3 Calc-alkalic dacite from near Cactus Flat
4 Calc-alkalic dacite from the surface of the Wild Horse Mesa basalt
5 Calc-alkalic dacite from the A stratigraphic layer found at the Donna deposit
6 Calc-alkalic dacite from the B stratigraphic layer found at the Donna deposit
7 Calc-alkalic dacite from the C stratigraphic layer found at the Donna deposit
8 Calc-alkalic dacite from the A stratigraphic layer found in Coso Valley
9 Calc-alkalic dacite from the B stratigraphic layer found in Coso Valley

TABLE 2. CIPW Norms of the Pumice Lapilli-Tuff, Coso Volcanic Field.

CIPW Norm	Sample, wt. %								
	1	2	3	4	5	6	7	8	9
Q	13.94	15.97	17.12	16.48	18.64	16.69	16.36	20.95	18.94
or	21.50	21.87	25.83	21.30	21.20	19.84	21.36	24.79	22.49
ab	39.16	38.48	36.06	37.67	38.40	41.24	41.39	32.76	35.89
an	12.53	11.94	13.28	13.33	11.36	14.01	11.18	13.66	14.82
di	6.25	7.79	1.26	6.03	6.55	2.39	5.09	1.69	1.06
hy	1.98	0.22	2.45	0.92	0.21	2.23	1.16	2.32	2.86
mt	3.05	0.00	0.76	0.74	0.79	0.11	0.10	0.49	0.55
hm	0.00	2.09	1.61	1.56	1.50	2.04	2.00	1.80	1.78
il	0.94	0.96	0.95	0.92	0.90	0.94	0.92	1.02	1.01
ap	0.62	0.46	0.63	1.00	0.39	0.47	0.39	0.47	0.55
Total	99.97	99.78	99.95	99.95	99.94	99.96	99.95	99.95	99.95

NOTE: Explanation of column headings:

1 Calc-alkalic dacite from Renegade Canyon
2 Calc-alkalic dacite from Deadman Canyon
3 Calc-alkalic dacite from near Cactus Flat
4 Calc-alkalic dacite from the surface of the Wild Horse Mesa basalt
5 Calc-alkalic dacite from the A stratigraphic layer found at the Donna deposit
6 Calc-alkalic dacite from the B stratigraphic layer found at the Donna deposit
7 Calc-alkalic dacite from the C stratigraphic layer found at the Donna deposit
8 Calc-alkalic dacite from the A stratigraphic layer found in Coso Valley
9 Calc-alkalic dacite from the B stratigraphic layer found in Coso Valley

TABLE 3. Major Oxide Analyses of Representative Volcanic Rocks From the Coso Volcanic Field.

Major oxide	Sample, wt. %								
	12	8	31	10	33	14	15	19	25
SiO_2	78.00	79.20	75.30	77.30	64.20	51.90	51.60	49.20	49.50
TiO_2	0.03	0.03	0.03	0.02	0.62	1.94	2.94	1.86	1.82
Al_2O_3	12.50	12.20	12.40	12.50	16.30	17.70	16.40	17.00	17.20
Fe_2O_3	0.86	0.57	0.71	0.57	4.00	10.20	11.40	10.40	10.70
MnO	0.03	0.03	0.03	0.06	0.07	0.17	0.18	0.18	0.20
MgO	0.03	0.02	0.06	0.06	3.40	4.60	3.90	7.80	4.60
CaO	0.41	0.41	0.60	0.28	4.41	7.70	7.21	10.60	9.50
Na_2O	4.20	3.90	3.90	4.50	4.30	3.80	3.50	3.70	3.40
K_2O	3.60	3.30	4.80	3.70	2.80	1.50	1.40	1.40	1.20
P_2O_5	0.01	0.01	0.01	0.01	0.18	0.41	0.53	0.51	0.50
loss	0.38	2.08	2.91	0.54	1.21	0.01	0.40	0.16	0.80
Total	100.05	101.75	100.75	99.54	101.49	99.93	99.46	102.81	99.42

NOTE: Explanation of column headings:

12 Calc-alkalic rhyolite from the perlitic domes
8 Calc-alkalic rhyolite from the perlitic domes
31 Calc-alkalic rhyolite from the perlitic domes
10 Calc-alkalic rhyolite from an old dome north of Coso Hot Springs
33 Calc-alkalic andesite from Haiwee Ridge
14 Calc-alkalic basalt from a flow in the Coso volcanic field
15 Calc-alkalic basalt from a flow in the Coso volcanic field
19 Alkalic basalt from a flow in the Coso volcanic field
25 Calc-alkalic basalt from a flow in the Coso volcanic field

TABLE 4. CIPW Norms of Representative Volcanic Rocks From the Coso Volcanic Field.

CIPW Norm	Sample, wt. %								
	12	8	31	10	33	14	15	19	25
Q	38.90	43.00	33.79	36.30	15.07	1.26	6.21	8.27	-----
C	0.97	1.49	-----	0.60	-----	-----	-----	-----	-----
or	21.27	19.50	28.98	21.86	16.54	8.86	8.27	-----	7.24
ab	35.53	32.99	33.72	38.07	36.38	32.15	29.61	23.43	29.39
an	1.96	1.96	2.19	1.32	16.90	26.80	24.90	25.64	28.73
wo	-----	-----	0.14	-----	-----	-----	-----	-----	-----
di	-----	-----	0.32	-----	2.97	7.04	5.93	18.89	13.08
mt	0.02	0.08	0.00	0.14	3.07	4.98	6.43	4.87	4.91
hm	0.84	0.56	0.72	0.47	-----	-----	-----	-----	-----
il	0.05	0.05	0.07	0.03	1.17	3.68	5.58	3.50	3.53
ap	0.02	0.02	0.02	0.02	0.41	0.94	1.22	1.18	1.18
hy	0.07	0.04	-----	0.14	7.54	13.48	10.17	-----	10.89
ne	-----	-----	-----	-----	-----	-----	-----	4.26	-----
ol	-----	-----	-----	-----	-----	-----	-----	-----	1.02
Total	99.63	99.69	99.95	98.95	100.05	99.19	98.32	90.04	99.97

NOTE: Explanation of column headings:

12 Calc-alkalic rhyolite from the perlitic domes
8 Calc-alkalic rhyolite from the perlitic domes
31 Calc-alkalic rhyolite from the perlitic domes
10 Calc-alkalic rhyolite from an old dome north of Coso Hot Springs
33 Calc-alkalic andesite from Haiwee Ridge
14 Calc-alkalic basalt from a flow in the Coso volcanic field
15 Calc-alkalic basalt from a flow in the Coso volcanic field
19 Alkalic basalt from a flow in the Coso volcanic field
25 Calc-alkalic basalt from a flow in the Coso volcanic field

Table 1 are very similar in chemical characteristics and are thought to be from the same magma source as the Haiwee Ridge andesite. A thickening of air-fall pumice toward Haiwee Ridge also demonstrates this point (Duffield, Bacon, and Roquemore).[13] To further compare the pumice lapilli-tuff to the other volcanic rocks in the Coso area, the samples from Tables 1 through 4 were plotted on two ternary diagrams. Figure 2 is an AFM diagram where A = (Na_2O + K_2O), F = (FeO + Fe_2O_3), and M = MgO. In this plot, a generally smooth trend from basalt to rhyolite can be seen; however, each individual rock type does not trend directly into the other. If there was differentiation of the magma, one might expect to see a more continuous line across the diagram. One possible explanation of clustering is that more than one magma pulse produced the Coso volcanics. The K-Ar dates also suggest two periods of eruptive activity.[9] A second explanation is that there are not enough chemical analyses to warrant good statistics. Further sample collecting would produce a larger suite of basalts and a few more dacites. A complete suite of rhyolite and only one andesite flow were analyzed in this study.

Figure 3 is another ternary diagram with normative or, ab, and an as end members. Again, clustering along the line is seen. The andesite falls close to the group of dacite samples and may therefore indicate a genetic relationship. The source magma(s) have become more silicious through time. Particularly the rhyolite domes show an increase in SiO_2 with younger K-Ar dates (Bacon and others).[14]

Harker silica variation diagrams (Figures 4 and 5) were constructed from the analytical data. The use of analytical values in constructing an ordinary variation diagram will show many characteristics of a group of rocks. The values for the oxides on the diagrams are plotted as the ordinate against the silica values as the abscissa. To define the petrographic province, the Peacock alkali-lime index (Figure 5) is used.

The data derived from Peacock's alkali-lime index (Figure 5) classify the rocks in the Coso volcanic field in the calc-alkaline suite (index = 56.75). These data include both Quaternary and Tertiary rocks. According to Verhoogen, the normal Al_2O_3 content of most continental tholeiitic magmas is between 13 and 15.5% by weight.[15] However, in the basalts of some provinces—the Pliocene-Holocene province of eastern Oregon for example—Al_2O_3 may exceed 18%. Such rocks represent what has been designated a high alumina basaltic magma type. Some of the older Coso rocks contain from 12 to 17% Al_2O_3 and are therefore probably related to a high alkali magma.

The von Wolfe diagram (Figure 6) shows the rocks that fall above or below the line of saturation. All rocks falling above the line contain an excess of silica, while those that fall below show a deficiency. Those rocks falling in the bounds of L-M-O are normal basalts, and one sample fell on the line L-O, which represents a rock composed of only feldspar and olivine. Samples in the field Ne-H-D are classified as trachydolerites and tephrites. All rocks above the E-K line have more quartz than required by the quartz-feldspar eutectic, so that first generation quartz separates. Acidic rocks, rhyolites, and dacites occur here. The E-K line is the natural boundary separating rhyolites from trachytes, and dacite from andesites.

[13] W. A. Duffield, C. R. Bacon, and G. R. Roquemore. "Origin of Reverse-Graded Bedding in Air-Fall Pumice, Coso Range, California," *J. Volcanol. Geotherm. Res.*, Vol. 5 (1979), pp. 35-48.

[14] C. R. Bacon, R. MacDonald, R. L. Smith, and P. A. Baedecker. "Pleistocene High-Silica Rhyolites of the Coso Volcanic Field, Inyo County, California," *J. Geophys. Res.*, Vol. 86, No. B11 (1981), pp. 10223-10240.

[15] J. Verhoogen. *The Earth: An Introduction to Physical Geology*. New York, Holt, Reinhart, and Wilson, 1970.

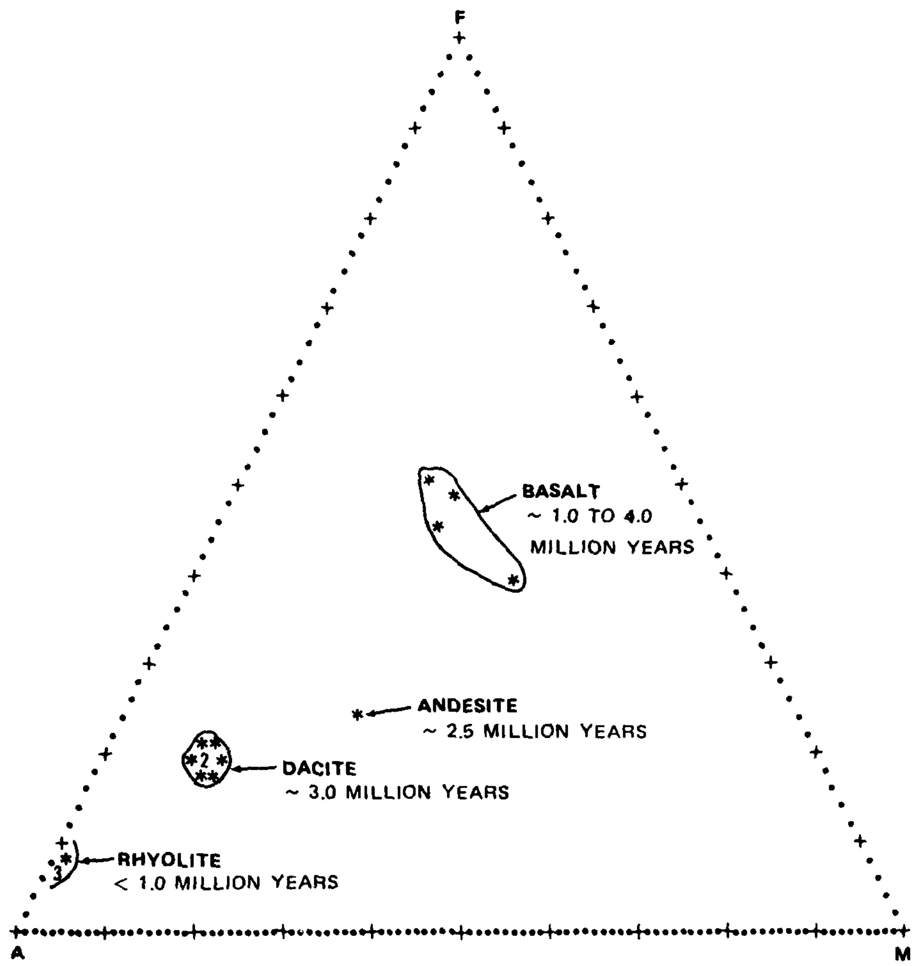

FIGURE 2. AFM Diagram of the Coso Volcanic Suite.

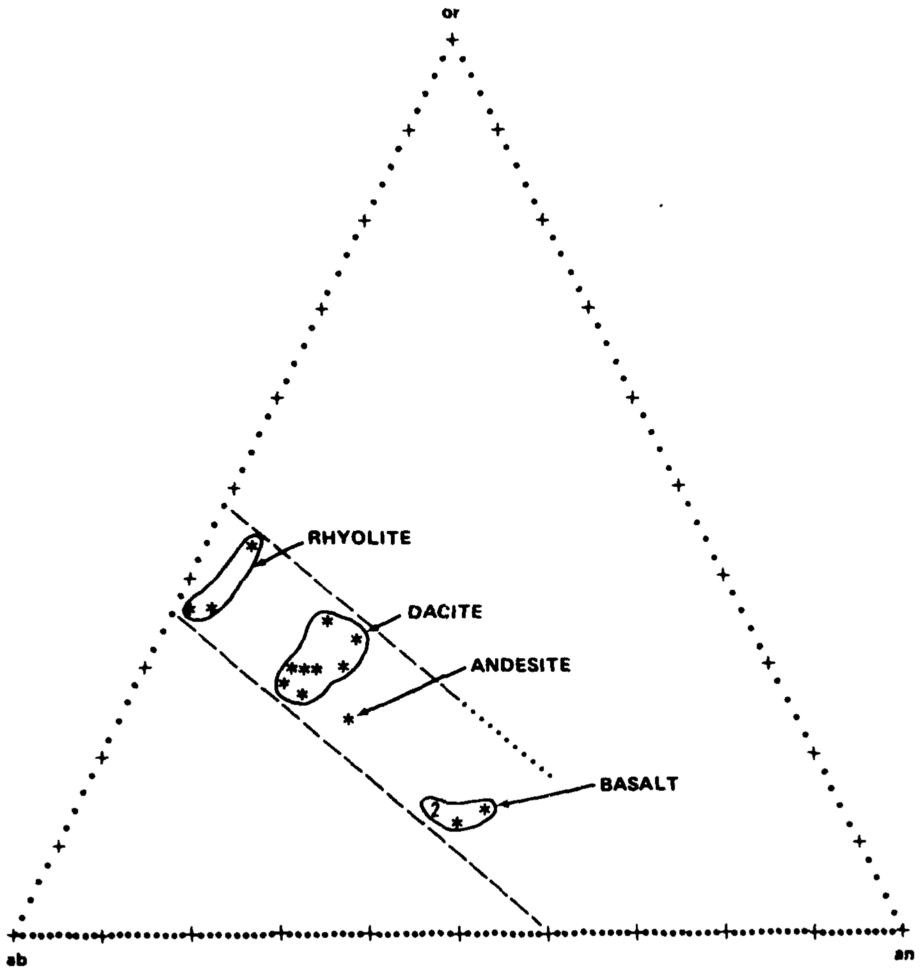

FIGURE 3. Normative or, ab, and an Ternary Diagram of the Coso Volcanic Suite.

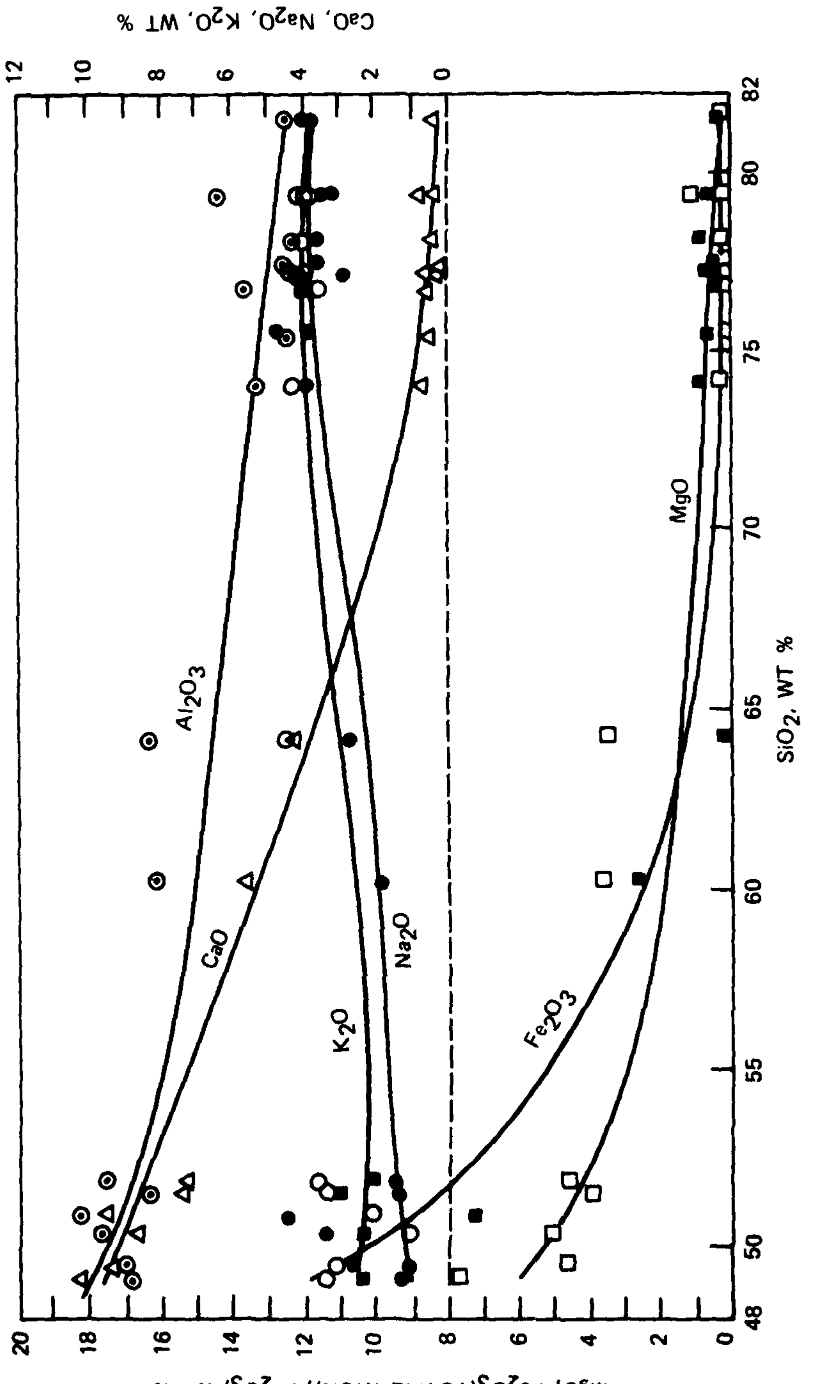

FIGURE 4. Harker Silica Variation Diagram.

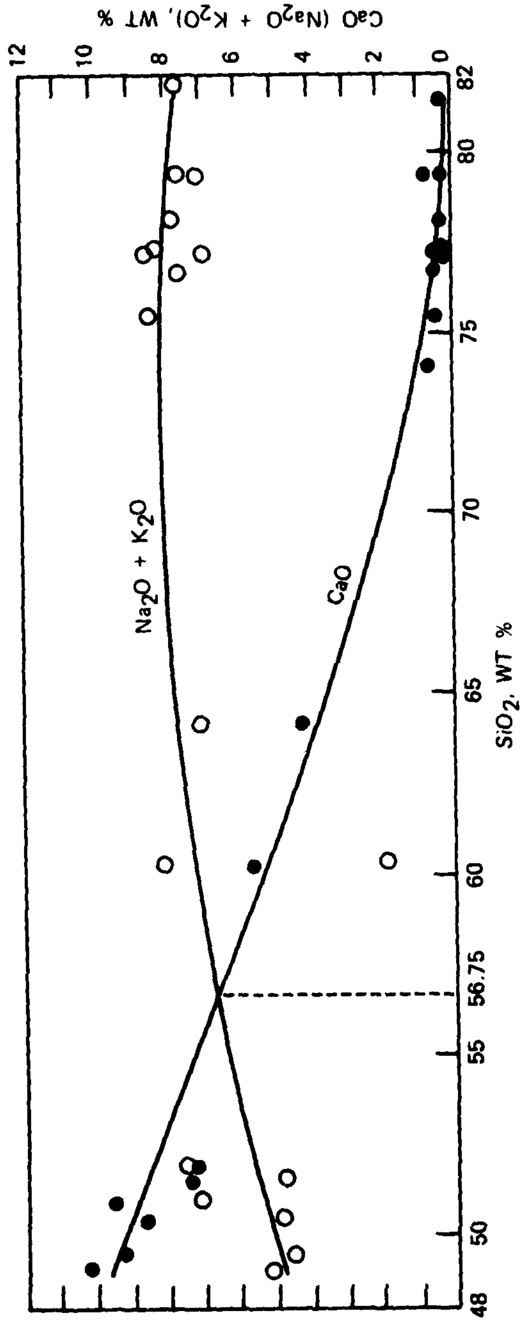

FIGURE 5. Silica Variation Diagram With the Peacock Alkali-Lime Index.

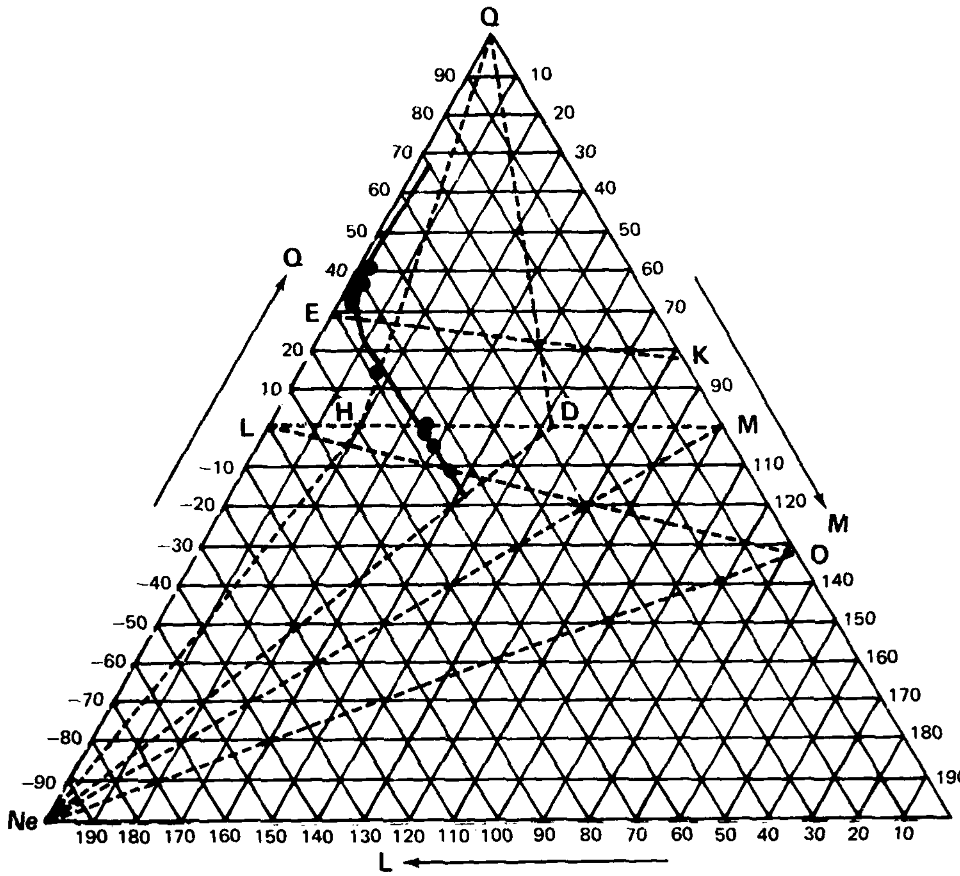

FIGURE 6. von Wolfe Diagram for the Coso Volcanic Suite.

The Harker variation diagram (Figure 4) shows lack of a good differentiation trend. The two definite clusters indicate that there may actually have been two magma pulses. This is further demonstrated by the K-Ar data.[9]

STRUCTURAL GEOLOGY

GRABEN VALLEYS AND TILTED BLOCKS

Rose Valley (Figure 7) separates the Coso Range from the Sierra Nevada. According to Healy and Press, Rose Valley represents a southward extension of the Owens Valley graben—a 240-kilometer zone along the Sierra Nevada front.[16] Their interpretation is consistent with later

[16] J. H. Healy and F. Press. "Geophysical Studies of Basin Structures Along Eastern Front of the Sierra Nevada," *Geophysics*, Vol. 5, No. 29 (1964), pp. 337-59.

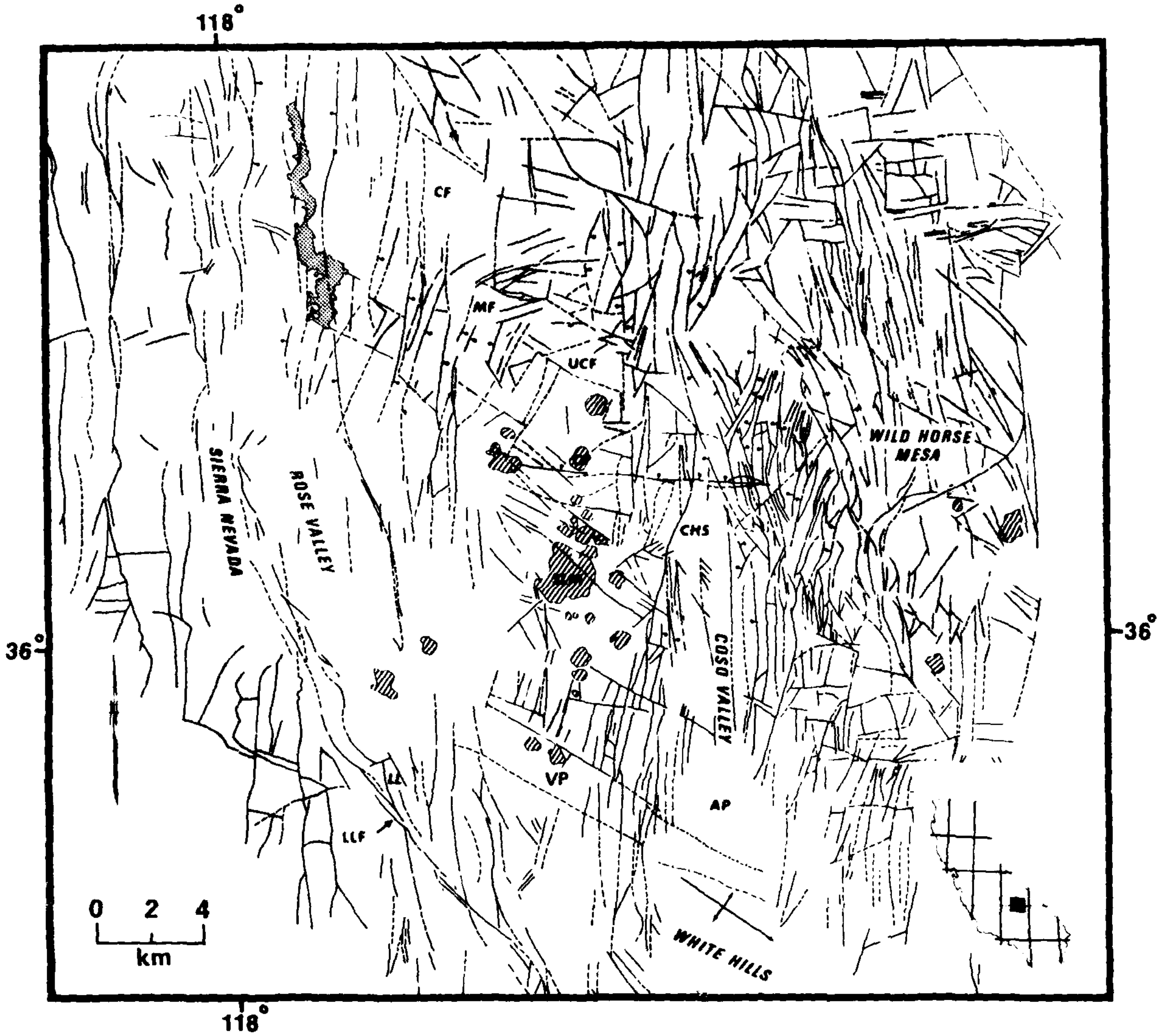

FIGURE 7. Index and Fault Map of the Coso Range and Adjacent Areas: CF, Cactus Flat; MF, McCloud Flat; UCF, Upper Cactus Flat; CP, Cactus Peak; CHS, Coso Hot Springs and Coso Basin (Coso Hot Springs Fault Bounds the Basin on the Northwest); SLM, Sugarloaf Mountain; AP, Airport Lake; LL, Little Lake; LLF, Little Lake Fault; and VP, Volcano Peak. The shaded area marks the topography above 5000 feet. The hatched areas are rhyolite domes and cinder cones.

work by D. B. Slemmons (private communication, 1979), who found that faults in the southern Owens Valley connect with those mapped in Rose Valley by Allen and others[17] and Roquemore.[1,18] The valley fill in the center of Rose Valley is over 1670 meters thick, which indicates substantial downfaulting on the valley margins. The west side of Rose Valley is bounded by the northeast striking Sierra Nevada frontal fault zone, where Duffield and Smith report over 650 meters of vertical movement.[19] Several step-faulted, west-tilted blocks of the Pliocene Coso Formation are to the east of Rose Valley (Power).[20] The faulting in Rose Valley is high-angle normal slip and results in low to moderately tilted fault blocks.

Coso Valley (Figure 7) is in the south central portion of the Coso Range. This graben valley is bounded on the west by the Airport Lake fault zone (west side of Coso Valley, Figure 7), which is a left stepping, en echelon, range-front fault zone. Two asymmetrical graben structures are within the zone of faulting, one of which is nearly 2 kilometers wide. The Airport Lake fault strikes N10°E to N20°E and dips from 50°E to vertical. The highly step-faulted Wild Horse Mesa bounds the east side of Coso Valley. Along this zone, thin sheets of Tertiary basalt, andesite, and dacite lava are broken by high-angle normal faults with a sinuous, left stepping, en echelon pattern.[9] The Coso Hot Springs fault (east of CHS in Figure 7) strikes N25°E with a dip of 45°SE to 55°SE and bounds Coso Valley to the north. It is actually a segment of the Airport Lake fault (Roquemore).[21] The left stepping en echelon displacement along this zone is consistent with orientation of the maximum comprehensive stress at about N30°E. The orientation of stress is rotated about 25° clockwise from that obtained by Carr for the Nevada test site to the east.[22]

STRIKE SLIP FAULTS

Most of the normal faults in the Coso Range trend north and have right slip displacement associated with them either as right oblique slip or as a left stepping en echelon pattern. Examples of right slip faults include the Airport Lake fault zone, Wild Horse Mesa, and the Little Lake faults. The Airport Lake fault zone is a prime example of an en echelon fault zone associated with right slip movement, as evidenced by right slip offset on a basalt flow[21] and by the typical left stepping en echelon pattern in Coso Valley. On Wild Horse Mesa a pattern of ramping, sinuous left stepping fractures step down west to the Coso Basin (CHS, Figure 7). The Little Lake fault (Figure 7) is perhaps the most spectacular example in this part of the Basin and Range; it has many of the typical landform characteristics of strike slip faults, including rhombic depressions, benches, side-hill ridges, linear troughs, and shutter ridges (Slemmons).[23] Similar manifestations of transcurrent motion east of Walker Lane in the Basin and Range province are not described in the literature.

[17] C. R. Allen, P. St.-Amand, C. F. Richter, and J. M. Nordquist. "Relationship Between Seismicity and Geologic Structure in the Southern California Region," *Bull. Seismol. Soc. Amer.*, Vol. 55 (1965), pp. 753-97.

[18] C. R. Roquemore. "Structure, Tectonics, and Stress Field of the Coso Range, Inyo County, California," *J. Geophys. Res.*, Vol. 85, No. 5 (1980), pp. 2434-40.

[19] W. A. Duffield and G. I. Smith. "Pleistocene History of Volcanism and the Owens River Near Little Lake, California," *J. Res. U.S. Geol. Surv.*, Vol. 6 (1978), pp. 395-408.

[20] W. R. Power, Jr. *Preliminary Report on the Geology and Uranium Deposits of Haiwee Ridge, Inyo County, California*. Washington, D.C., U.S. Atomic Energy Commission, 1958. 37 pp. (RME-2066, publication UNCLASSIFIED.)

[21] Naval Weapons Center. *Active Faults and Associated Tectonic Stress in the Coso Range, California*, by G. R. Roquemore. NWC, China Lake, Calif., August 1981. 70 pp. (NWC TP 6270, publication UNCLASSIFIED.)

[22] W. C. Carr. *Summary of Tectonic and Structural Evidence for Stress Orientations at the Nevada Test Site*. 1974. 53 pp. (U.S. Geological Survey Open File Report 74-176, publication UNCLASSIFIED.)

[23] D. B. Slemmons. *State-of-the-Art for Assessing Earthquake Hazard in the United States: Report 6, Faults and Earthquake Magnitudes*. Vicksburg, Miss., U.S. Army Engineer Waterways Experiment Station, 1977. (Paper 5-73-1, UNCLASSIFIED.)

WHITE HILLS ANTICLINE

The White Hills anticline (Figure 7), which strikes N65°W to N75°W, provides a clear representation of the stress field. It is perpendicular to the direction of maximum compressive stress inferred by the N15°E to N25°E faulting pattern (Figure 7). The Wilson Canyon fault, running parallel to and north of this fold, was active in pre-Quaternary time. Zbur reported the sense of movement on the Wilson Canyon fault to be left slip;[7] if that is true, however, it must be part of an older structural regime. If the fault is part of the present structural mechanism it would have to be a thrust fault. Airport Lake is a structural depression with a crude rhombic pattern. The White Hills anticline is the south boundary of the rhombohedron. The Wilson Canyon fault has been located in this area by seismic exploration methods,[7] and therefore the sense of movement remains speculative.

RATE AND STYLE OF VERTICAL AND HORIZONTAL DISPLACEMENT

VERTICAL DISPLACEMENT

Vertical displacements are expressed in the Coso Range as horst and graben structures, tilted blocks, and step faults. Vertical tectonic rates are very rapid, as two examples here show. First, a distinctive 2 500 000-year-old capping rhyodacite flow,[9] located above the Coso Formation, is offset 1600 meters at a site on the west flank of the Coso Range.[1] Determination of this offset is based on the present elevation of the rhyodacite flow and the location of the assumed same flow buried in Rose Valley, identified by geophysical methods.[16] If the two flows are the same, then the inferred rate of vertical movement based on this offset is 1.8 mm/yr. Second, on Wild Horse Mesa (Figure 7), another area of tectonic extension and associated step faults date the lava flow at about 3 000 000 years. The total offset of this flow has not been determined because the lowest downdropped block is buried in alluvium of the Coso Basin, but it is at least 600 meters. This offset gives a minimum rate of vertical deformation on Wild Horse Mesa at 0.2 mm/yr.

HORIZONTAL DISPLACEMENT

Geomorphological evidence can be used to estimate horizontal rates of offset on the Little Lake and Airport Lake faults. The Little Lake fault extends northward from near the Garlock fault at a strike of N40°W and is best exposed near the settlement of Little Lake, where a young lava flow is offset. The Little Lake fault is predominantly right slip and offsets by 250 meters a basalt flow dated at 440 000 years.[19] The displacement, which indicates an average slip rate of 0.6 mm/yr, is calculated by schematic reconstruction of the rhombic depressions, plus measurements of right slip offset in a basalt cliff. The lava flow is modified by stream erosion, therefore the measured amount of horizontal displacement is a minimum value. A shutter ridge along the fault is offset only 30 meters, but diverted wash channels contain highly crushed landslide material from the Sierra Nevada. This landslide material must be younger than the 440 000-year basalt because it is not eroded by the ancient Owens River. An offset basalt flow that has been dated by K-Ar provided a measured displacement of 125 meters on the Airport Lake fault. On the basis of K-Ar dating, this flow is about 1.07 ± 0.14 million years old (Qbc),[4] which implies an offset of 0.1 m/yr on this fault. Horizontal deformation in the Coso Range is consistent with a transition between the San Andreas fault and Coso Basin and Range extension.

FUMAROLIC ACTIVITY ALONG BASIN AND RANGE FAULTS IN THE COSO RANGE

Austin and others noted radial faults projecting outward toward the circumference of a feature in the Coso Range that they identified as a ring structure.[24] In this interpretation one would expect fumarolic activity to concentrate along these radial faults and that motion on them would be normal faulting since they are tensional in this model. Most of the dozens of known fumaroles in the Coso Range are associated with faults. The faults in the Coso Range that are associated with hot springs have significant components of oblique slip. As two examples, consider the Airport Lake fault zone with right slip offset of a basalt flow and the Coso Hot Springs fault with a left stepping en echelon pattern. Both of these faults contain the main concentration of hot springs in the region and have a sense of strike slip displacement that is consistent with the regional tectonic stress pattern. The strike slip displacement is not required by ring fault or caldera-like features.

Based on heat flow (Coombs),[25] P-wave delays (Reasenberg and others),[26] electrical methods (Jackson and O'Donnell),[27] aeromagnetic and gravity surveys (Plouff and Isherwood),[28] and ground magnetics (Roquemore, unpublished data), the heat source in the Coso volcanic field appears to be centered near Devils Kitchen (Plate 1). Comparison of the geophysical data indicates a structural connection between Devils Kitchen, Coso Hot Springs, and the Wheeler Prospect (Airport Lake fault).[21] These faults may represent a good geothermal target, depending on their permeability.

[24] C. F. Austin, W. H. Austin, Jr., and G. W. Leonard. *Geothermal Science and Technology—A National Program*. China Lake, Calif., Naval Weapons Center, 1971. 95 pp. (Paper 45-029-72, UNCLASSIFIED.)

[25] J. Coombs. "Heat Flow in the Coso Geothermal Area, Inyo County, California," *J. Geophys. Res.*, Vol. 85, No. 5 (1980), pp. 2411-24.

[26] P. Reasenberg, W. Ellsworth, and A. Walter. "Teleseismic Evidence for a Low-Velocity Body Under the Coso Geothermal Area," *J. Geophys. Res.*, Vol. 85, No. 5 (1980), pp. 2471-83.

[27] D. B. Jackson and J. E. O'Donnell. "Reconnaissance Electrical Surveys in the Coso Range, California," *J. Geophys. Res.*, Vol. 85, No. 5 (1980), pp. 2502-16.

[28] D. Plouff and W. F. Isherwood. "Aeromagnetic and Gravity Surveys in the Coso Range, California," *J. Geophys. Res.*, Vol. 85, Vol. 5 (1980), pp. 2491-2501.

Appendix A

SAMPLE LEGEND FOR PLATE 1

Map No. (Plate 1)	Rock type	Sample No. (Tables 1-4)
1	silicious sinter	...
2	granitic	...
3	mafic dike	...
4	granitic	...
5	granitic	...
6	tuff ring	...
7	tuff ring	...
8	rhyolite dome	8
9	rhyolite dome	...
10	old rhyolite flow	10
11	basalt/andesite	...
14	basalt	14
15	basalt	...
16	tuff	1
17	tuff	2
18	tuff	...
19	basalt/andesite	19
20	tuff	5
21	tuff	6
22	tuff	7
23	tuff	8
24	tuff	9

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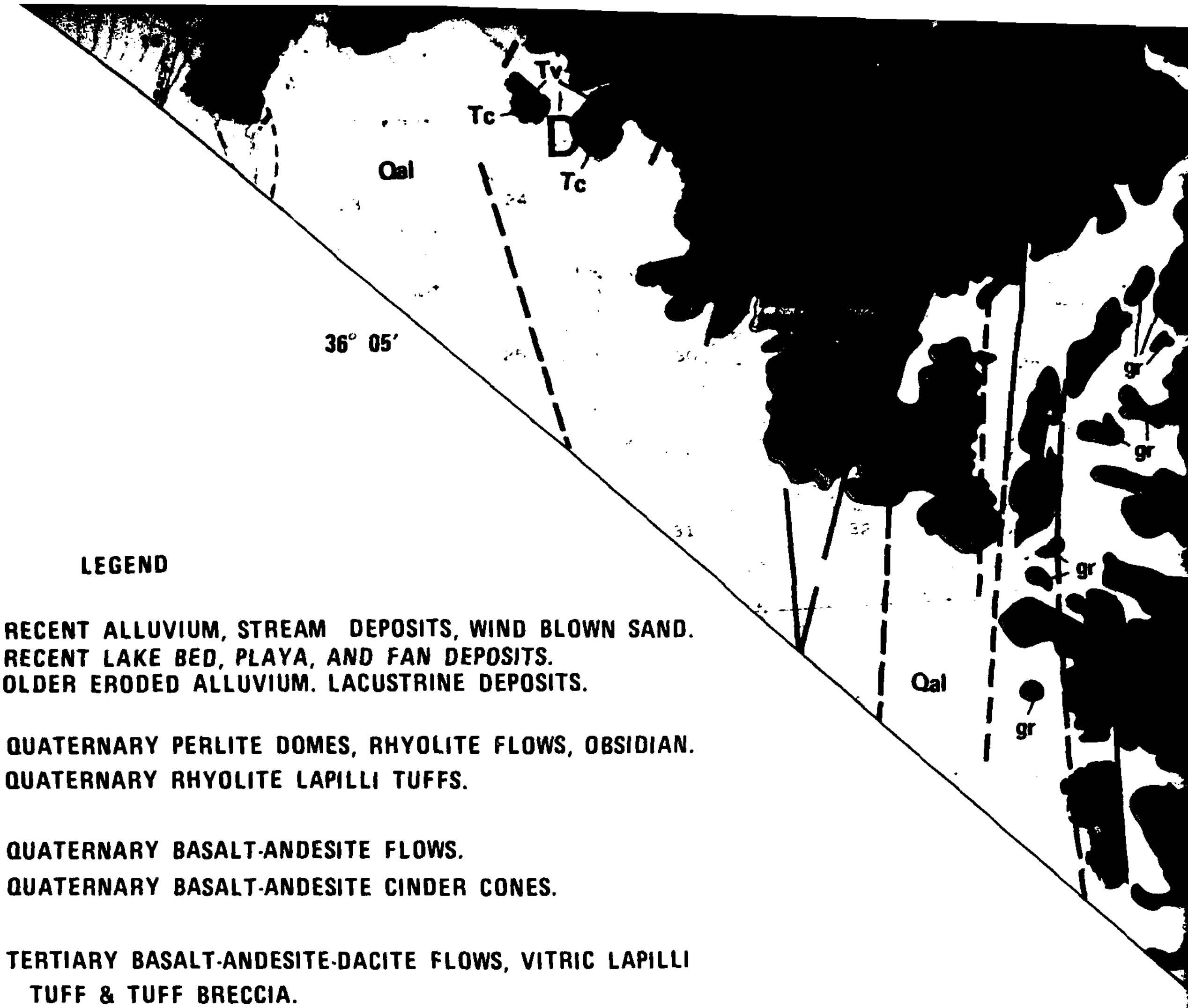


LEGEND

RECENT ALLUVIUM, STREAM DEPOSITS, WIND BLOWN SAND.
RECENT LAKE BED, PLAYA, AND FAN DEPOSITS.
OLDER ERODED ALLUVIUM. LACUSTRINE DEPOSITS.

QUATERNARY PERLITE DOMES, RHYOLITE FLOWS, OBSIDIAN.
QUATERNARY RHYOLITE LAPILLI TUFFS.

QUATERNARY BASALT-ANDESITE FLOWS.
QUATERNARY BASALT-ANDESITE CINDER CONES.

TERTIARY BASALT-ANDESITE-DACITE FLOWS, VITRIC LAPILLI TUFF & TUFF BRECCIA.

TERTIARY PUMICE LAPILLI TUFF & LITHIC VITRIC TUFF.

TERTIARY COSO FORMATION: LAKE BED DEPOSITS, SANDSTONE, RHYOLITE TUFF & TUFF BRECCIA.

MESOZOIC ACIDIC INTRUSIVES, MIGMATITE ROOF PENDANTS, METAMORPHIC ROCKS.

FAULT TRACE (DASHED WHERE CONCEALED)
BALL ON DOWN THROWN SIDE. ARROWS SHOW RELATIVE HORIZONTAL MOVEMENT.

GEOLOGIC CONTACT (DASHED WHERE APPROXIMATE)

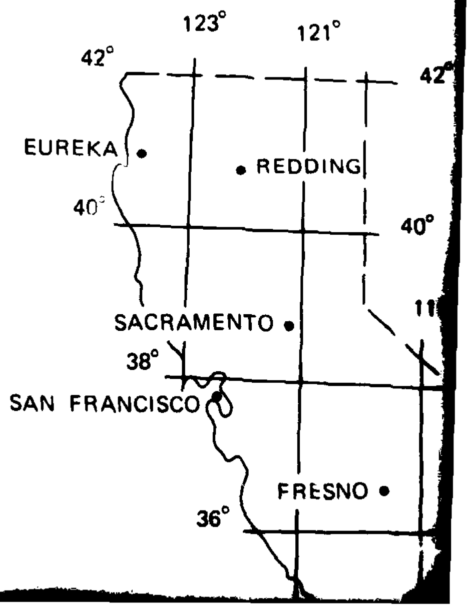
● 2 SAMPLE LOCATIONS

LANDSLIDE

STRIKE OF VERTICAL JOINTS.

STRIKE & DIP OF BEDDING.

⊕ HORIZONTAL BEDDING



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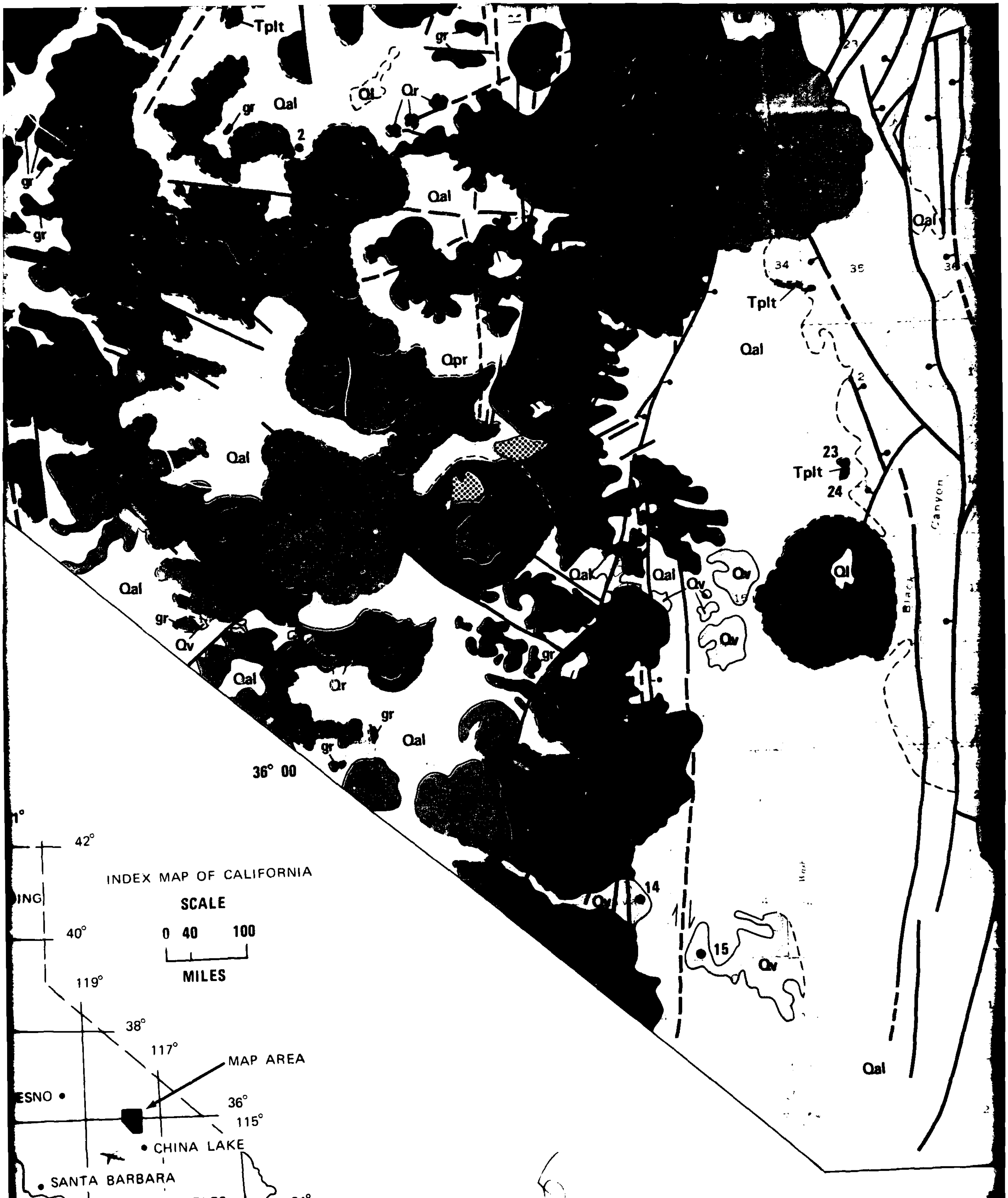
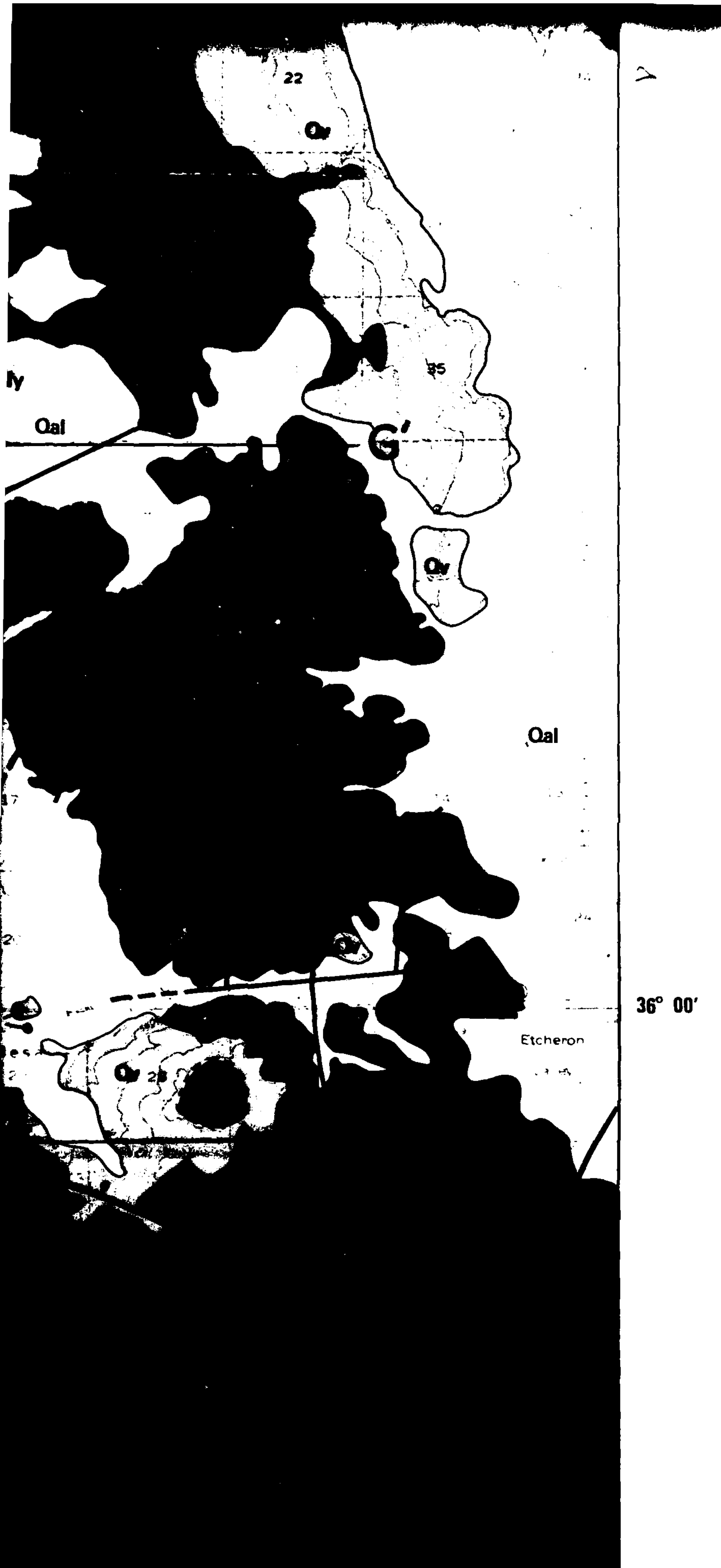


Geologic & Structural Ma

GEOLOGY GENERALIZ

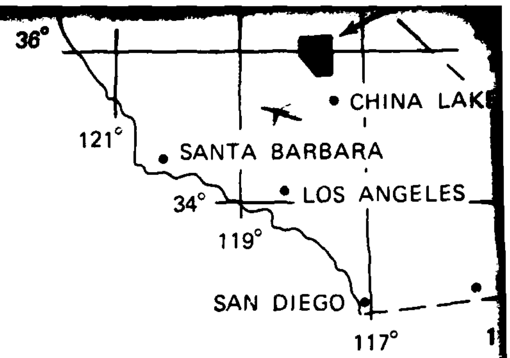


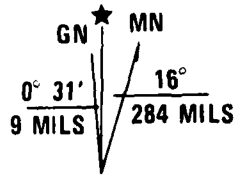
Y GENERALIZED IN PART FROM UNPUBLISHED MAPPING BY

P. St. AMAND 1975

⊕ **HORIZONTAL BEDDING**

HYDROTHERMALLY ALTERED





UTM GRD AND 1954 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

EL CENTRO

115°

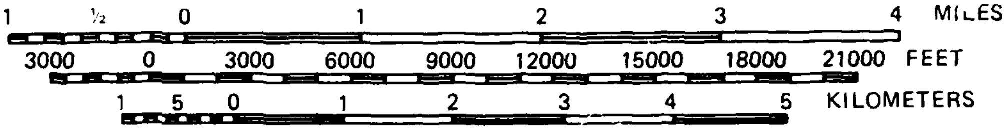
Geologic & Structural Map of Par[t]
Coso Mountains, California

BASE MAP 15' QUADRANGLES; LITTLE LAKE, MOUNTAIN SPRINGS CANYON, HAIWEE RESERVOIR, COSO PEAK.

by Glenn R. Roquemore

CARTOGRAPHER
PATRICIA F. O'DELL

SCALE



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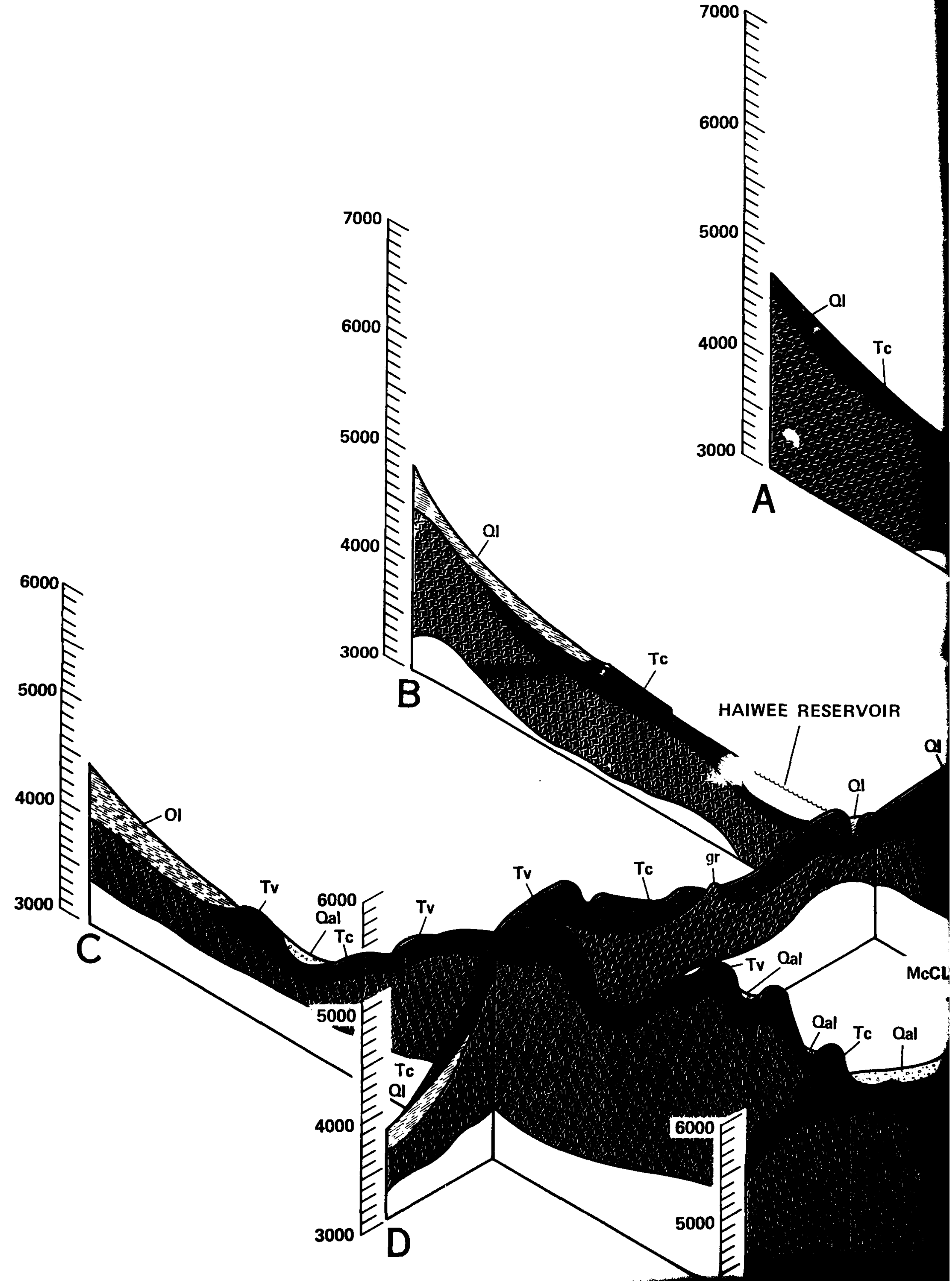

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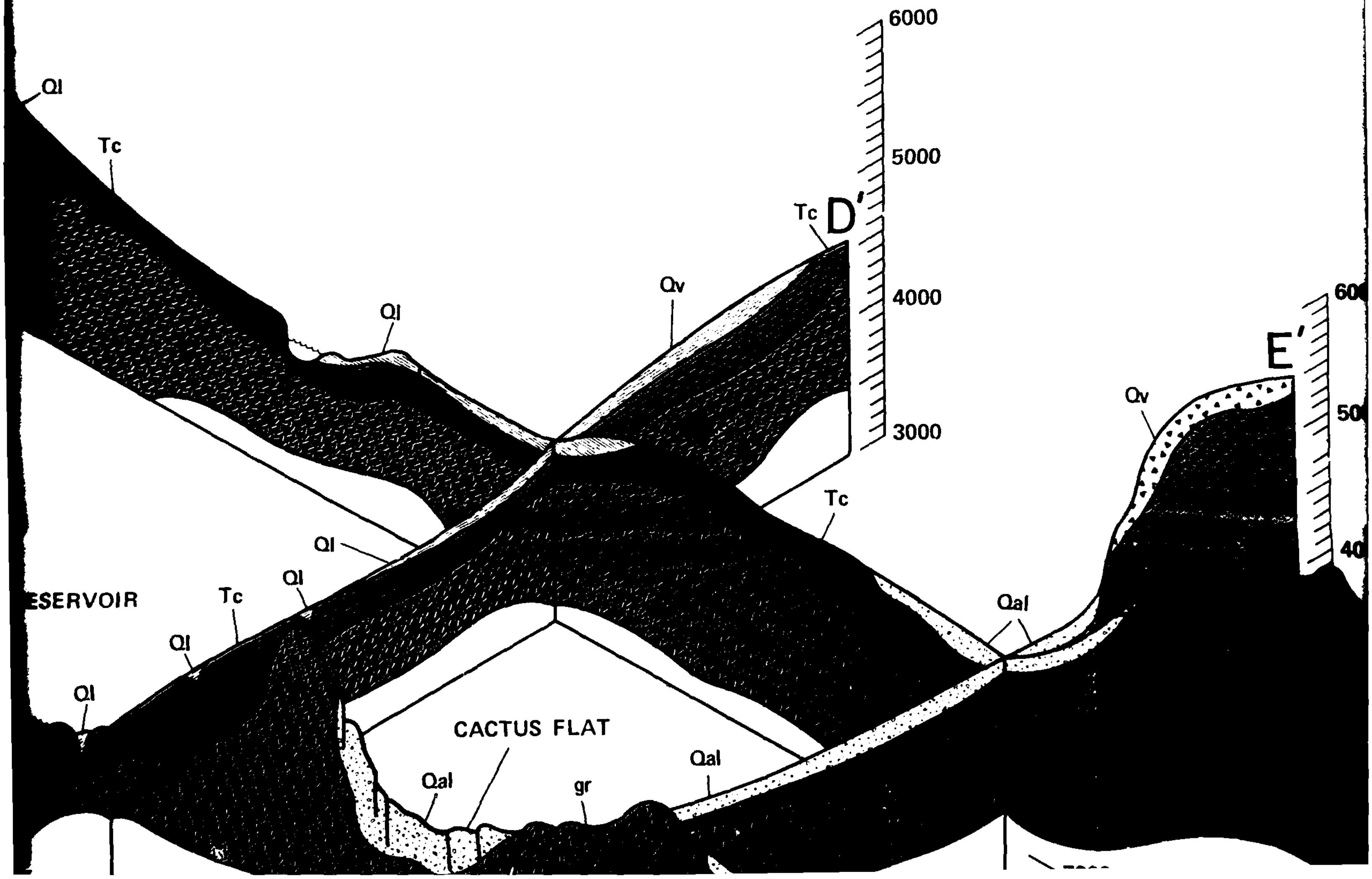
Plate 2



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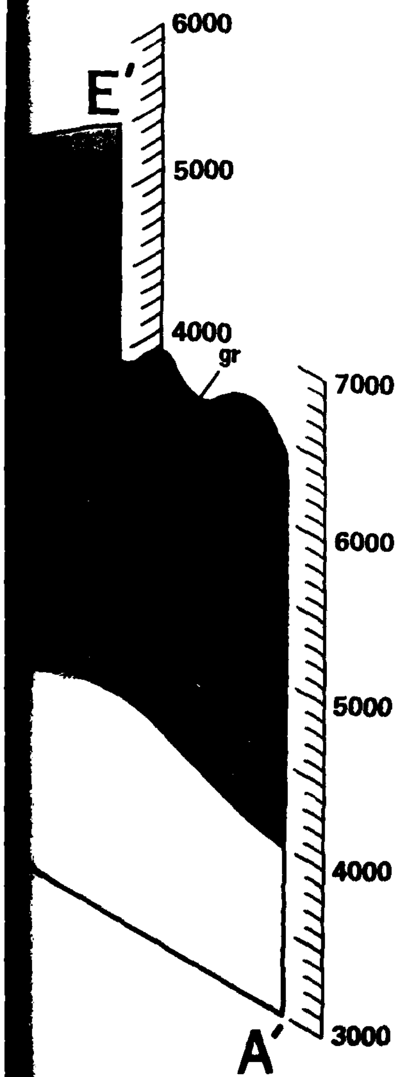

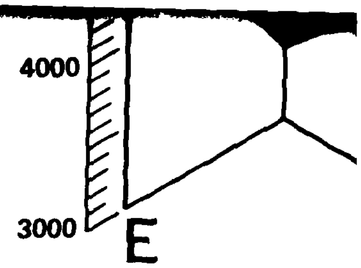

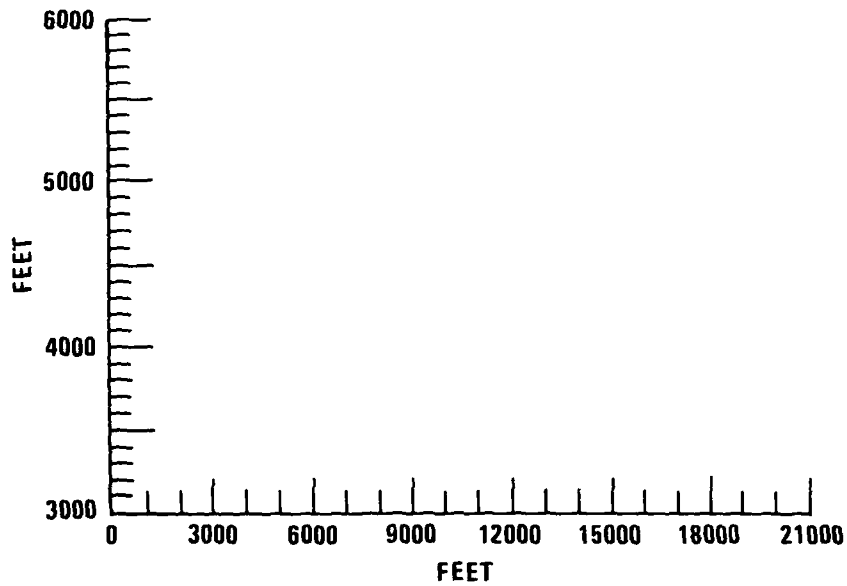

ROCK UNITS ARE COLOR CODED TO
THE GEOLOGIE MAP– PLATE 1

Geologic Cross Section of Part of the
California

by

Glenn R. Roquemore

1979

CARTOGRAPHER
PATRICIA F. O'DELL

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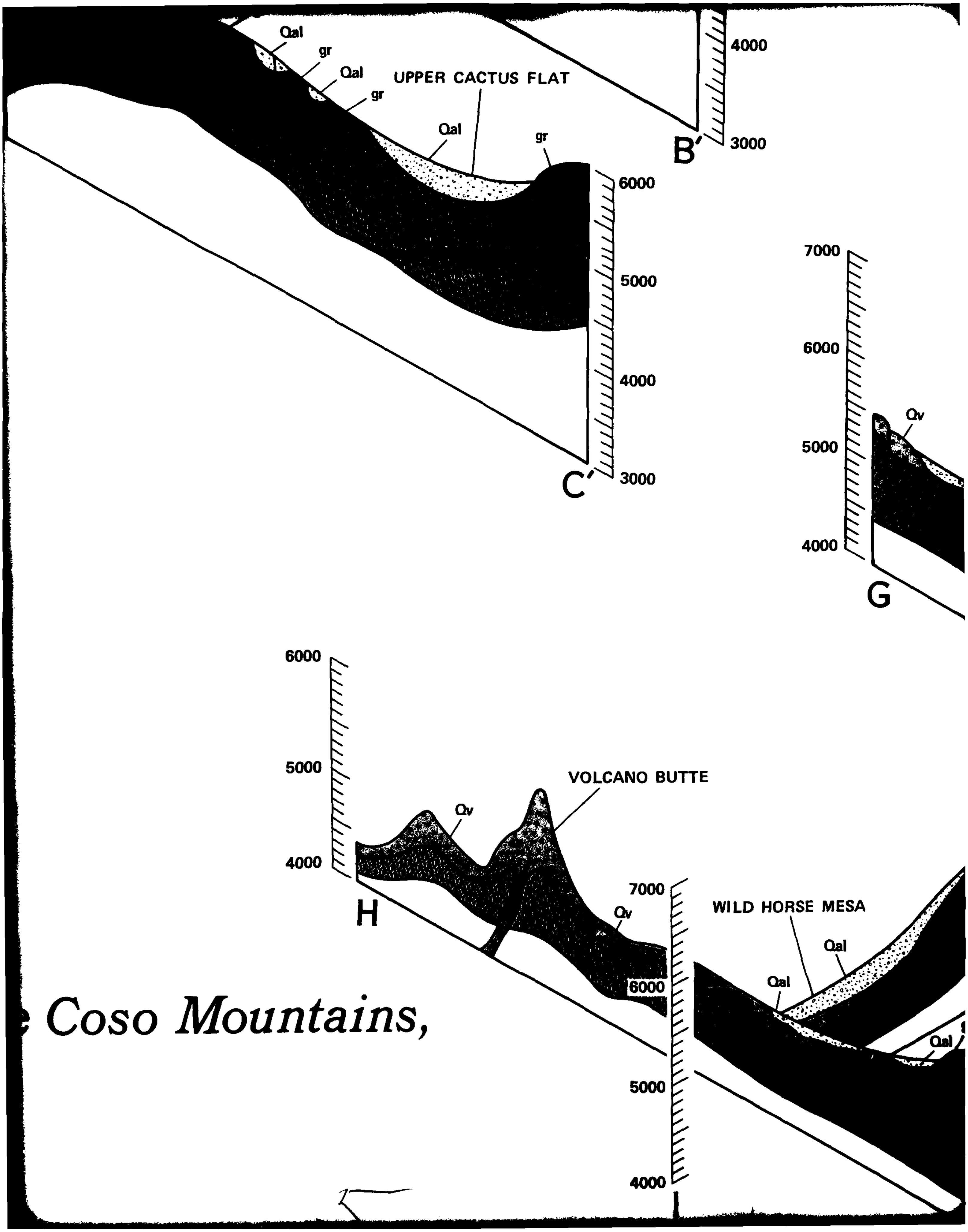
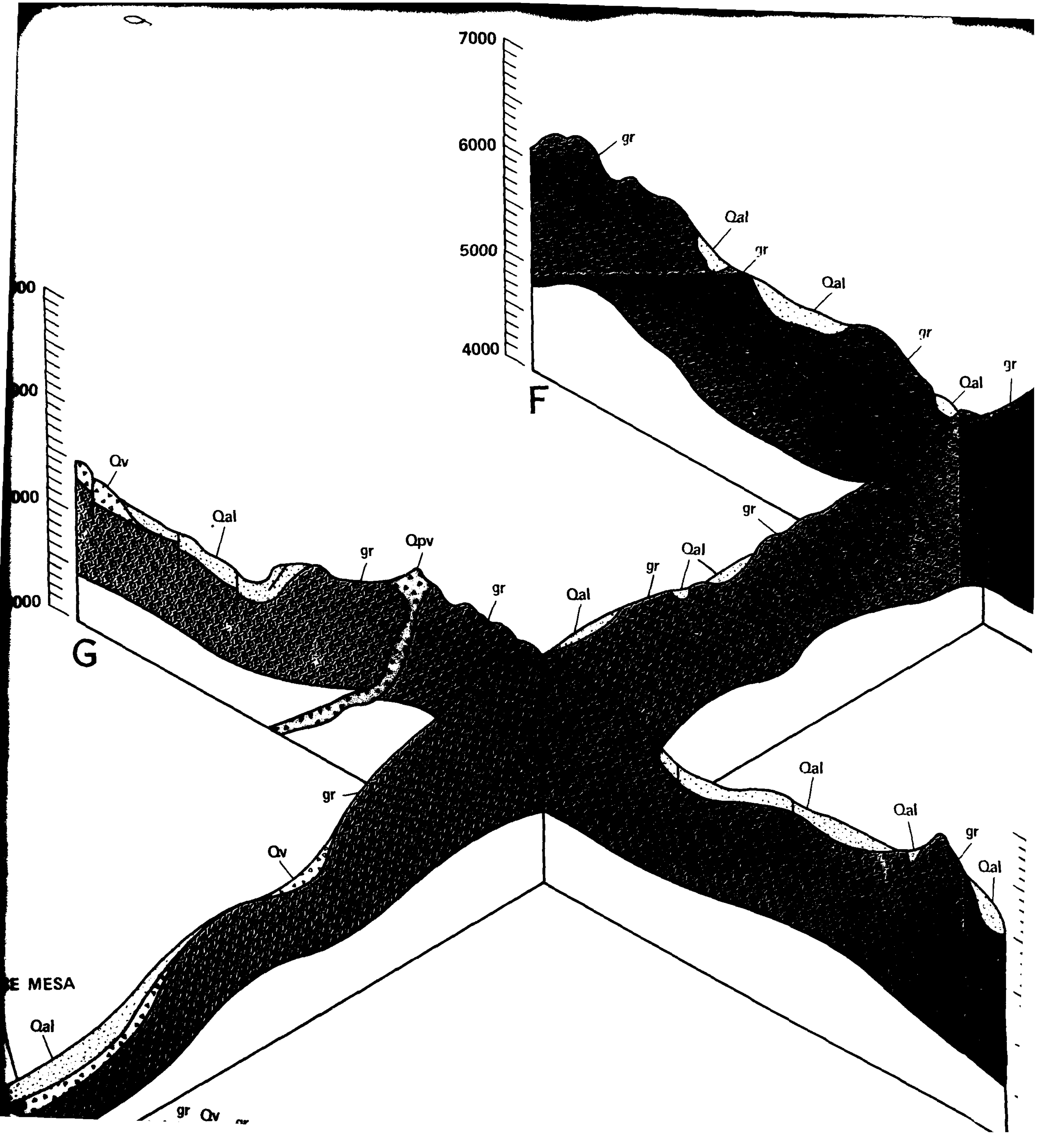


e Coso Mountains,



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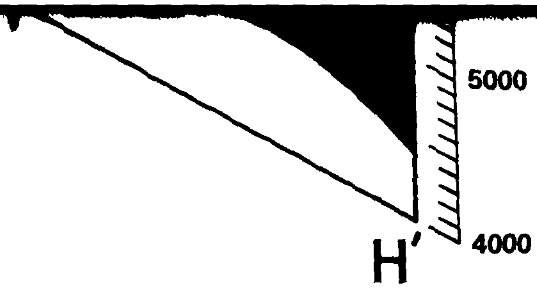

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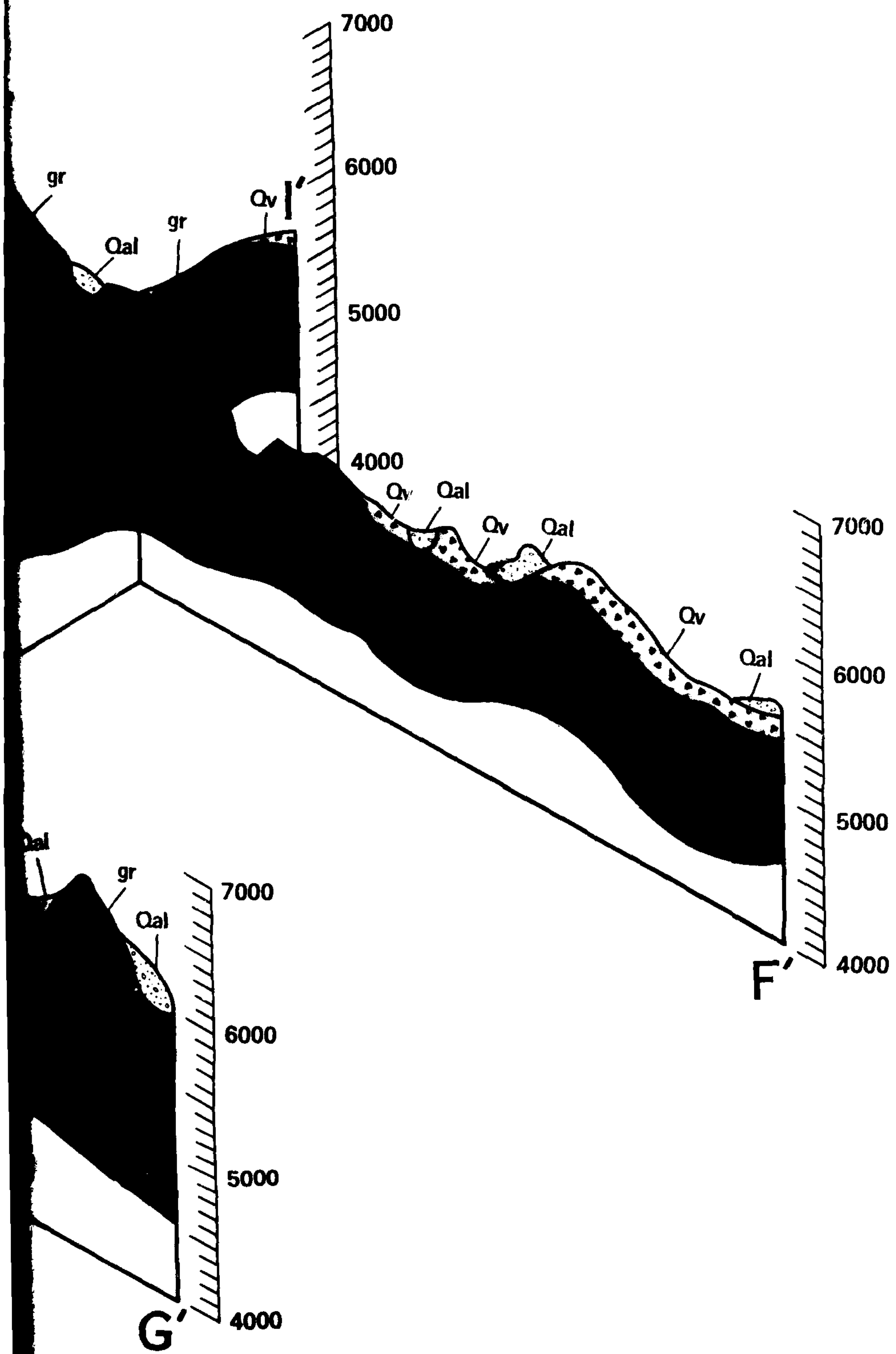

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